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"It's just a theory": trainee science teachers' misunderstandings of key scientific terminology

James David Williams

Abstract

Background: This article presents the findings from a survey of 189 pre-service science teachers who were asked to provide definitions of key scientific terms ('theory'; 'fact'; 'law'; 'hypothesis'). The survey was a scoping and mapping exercise to establish the range and variety of definitions.

Methods: Graduates on a pre-service science teacher training course were asked to complete a short, free response survey and define key science terminology a >95% response rate was achieved and respondents definitions were categorised according to a best fit model.

Results: In some cases, definitions contrary to accepted scientific meanings were given. In other cases, terminology was defined in a wholly non-scientific way, e.g., one-fifth of the respondents defined a 'law' in the context of rules that govern society rather than in a scientific context. Science graduates' definitions and their understanding of key terminology is poor despite their study of science in formal university settings (with many respondents being recent science graduates).

Conclusions: Key terminology in science, such as 'theory', 'law', 'fact', 'hypothesis', tends not to be taught and defined with consideration for the differences in meaning that different audiences/users give to them. This article calls for better instruction for pre-service science teachers' in the importance of accurate and precise definitions of key science terminology in order to better differentiate between the scientific and colloquial usage of key terms.

Keywords: Scientific language, Scientific definitions, Theory, Law, Fact, Hypothesis

Background

This article reports the results of a survey of science graduates training to be science teachers and their understanding of key scientific terms such as 'theory', 'hypothesis', 'law' and 'fact'. A critical aspect of science is precision. Precision in measurement is taught to students and ideas of accuracy are also imbued during science teaching and learning. What this research shows is that precision and accuracy in the language used to deliver science is likely to be less common due to the variability in how graduates conceive of and define key science terms.

Language plays an important role in developing scientific understanding (Lemke, 1990, Wellington and Osborne, 2001, Gyllenpalm *et al.*, 2010, Webb, 2010, Snow, 2010). The language of science has developed over centuries and its use as a means of communicating between scientists and as a way of organizing scientific thought (e.g., through the establishment of systematic names for plants, animals and units of measurement), are important aspects of how science is viewed by non-scientists - as a technical, precise discipline that avoids personal feelings or attitudes (Crosland, 2006).

Scientific concepts are conveyed by teachers using scientific language, frequently supported by hands-on activities in a laboratory setting. Scientific language can present difficulty for high school students; the grammar of scientific language increases difficulties in reading scientific texts. For example, Halliday (2003) states that written scientific texts often contain *'…a pile up of nouns'* (p.159) which makes it hard for both native and non-native English speakers to understand. This is not peculiar to the English language, he notes, with scientific forms in other languages also posing difficulty.

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Attention to scientific language by teachers of secondary science has been advocated by Wellington and Osborne (2001) and its importance in science education is emphasized. They liken the work of science teachers to that of language teachers and consider learning science as similar to learning a new language. What is less well documented is the understanding of scientific language by science teachers and, in particular, their understanding of some of the basic technical terms.

Science teachers are not professional scientists *per se*. Some may enter the teaching profession having first worked as a professional scientist, in either research or industry. Many will train as science teachers having acquired a science-based degree, but with no post-degree training or work in science or as a scientist. How they use the language of science and their own acquired definitions of key terminology may well be affected by their experience with science and the degree of academic or industrial training they have received in science.

Research question

The key research question for the study being reported here was *'how do science teachers define key scientific terms that are in use in science teaching and learning?'*

The goal of scientific language, according to Reeves (2005), is to be free of connotations that reflect or create cultural bias and emotional attachment, but as Kent reported in the late 1950s, the goalposts of precision in the meanings of scientific vocabularies are ever shifting.

> *Historical facts show that the meanings of words, in scientific as well as non-scientific language, are always flexible, never precisely precise, always somewhat vague, always changing… words have precise meanings only from the limited viewpoint of a fixed now and a single user.* (Kent, 1958 p.185)

Reeves (2005) describes three problems that occur with the use of scientific terminology: the definition of the same term in different ways by scientists from different sub-fields of science; the use of vague terms which can result in different definitions of those terms by different people; and the use of inappropriate terms in scientific language. It is the first category of problem that is most relevant to the study reported on here and is the basis of the research question.

Common understandings and misunderstandings

Do all science teachers have a common understanding of key scientific terminology? For certain aspects of science, such as high school definitions of an atom, or the process called photosynthesis, it is reasonable to assume that there is a general, common understanding which is demonstrated through the textbooks and examination specifications. A concept such as photosynthesis will have ascribed to it a general meaning for the purposes of school science, for example: *'photosynthesis is the process whereby green plants convert carbon dioxide and water into useful carbohydrates using energy from sunlight, producing oxygen as a waste by-product'*. Few, if any, science teachers would disagree with such a definition at a very basic level, yet all science teachers know that the actual process of photosynthesis is very complex and made up of multiple stages.

In school science a range of texts is used with children, from formal science textbooks, to science-based articles on the internet, in magazines, as well as newspaper reports (actual or online) of scientific discoveries and ideas. This latter type of text may be particularly useful when trying to engage children in scientific issues and everyday science contexts. The engagement of children in the content of science using the medium of popular articles is considered as a vital component to good science teaching (Teaching Learning and Research Programme, 2006). Yet the manner in which scientific terms, such as 'theory' and 'hypothesis' are used within, for example, newspaper reports may be very different from their use in science classes, posing problems both for the teacher and the learner. Working scientists, who may not be science educators, can use terminology inconsistently, especially if we compare how terms are used across different scientific disciplines (Tenopir and King, 2004). When science is reported in the press, it is unlikely that the journalist will be a trained scientist. As such, their own definitions of key scientific terms may be at odds with those of the scientist or the science being reported.

Confusion with scientific language in the media

Science reporting in the media must use the language of science - sometimes explained in simple terms - to convey meaning to the story being reported. While many technical terms will be defined, explained or otherwise put into everyday language, key scientific terminology, such as 'theory' and 'hypothesis' are often used in a more problematic way.

The following story in *The Times* (London) newspaper concerns a scientist's proposition that life forms on Earth that exist in ecological niches where 'normal' life forms would be unable to exist (e.g., extremophiles living near hydrothermal vents) increase the chances of alien life forms being found on other planets, and that these extremophiles themselves may be considered as alien life forms on earth.

British physicist Paul Davies and colleagues may not quite have found alien life on Earth, they have certainly found life as we never knew it before.

The discovery springs from Professor Davies's long quest for extraterrestrial intelligence and, specifically, his theory that "weird" microbes that belong to a completely separate tree of life, dubbed the "shadow biosphere", could be present in isolated ecological niches in which ordinary life struggles to survive.

The report goes on

The trick, of which Professor Davies is a master, is turning wild speculation into credible scientific hypothesis. Of course, if a hypothesis is shown to be wrong, it must be discarded, not clung to with the irrational desperation of the conspiracy theorist. (Devlin, 2010 p.36)

In this report, an initial 'theory' is transformed into a 'hypothesis' in the matter of a few lines of prose. More damaging, the concept of 'theory' here could be equated with 'wild speculation'. This may well be an example of the mixing of a vernacular use of 'theory' by the journalist with a scientific use of 'hypothesis'. When the basic terminology of science is used so interchangeably, it can promote confusion between the meaning of 'theory' and 'hypothesis'. In vernacular use, the term 'theory' refers to an untested idea, a speculation even. In science, such untested ideas will normally be referred to as 'hypotheses'.

Method

Against the backdrop of the above concerns, and with a view to establishing levels of understanding/confusion in pre-service science teachers' definitions of key scientific terminology, a series of surveys of science graduates, who were enrolled on a pre-service teacher education program in an English university, were undertaken over a four-year period.

During a two-week induction program at the start of their training to become qualified science teachers, each graduate was asked to participate in the study. Participation was voluntary and data were collected anonymously. Part one of the survey asked for basic personal information, such as their age, highest level of qualification and subject and high school qualifications. Part two asked about respondents' understanding of 'scientific method'. Graduates were allowed to communicate their ideas by narrative text, flow diagrams and mind or concept maps, or in any way which suited them. Part three, the section most pertinent to this article, simply required respondents to define four key scientific terms: 'fact'; 'law'; 'hypothesis'; 'theory'. Science graduates were asked to provide their own definitions, without reference to texts, smart phones or other students.

The timing of the survey was important as the induction program for the pre-service teacher education course includes taught sessions on the Nature of Science and the Nature of School Science, which also include discussion of the language of science and scientific meanings. Surveys were completed prior to the taught sessions. Survey questionnaires were completed by four successive annual intakes (2005 to 2009) of science graduates. Data were analyzed descriptively so as to identify major areas of ambiguity and confusion.

Respondent profile

In total, 189 surveys were completed by science graduates entering a pre-service initial teacher training program. This represents a >95% return rate over the period specified. The surveys were completed at pre-seminar sessions during the teachers' induction program. Completion of the survey was anonymous and voluntary, with the purpose of the survey explained prior to completion.

Entrants in the pre-service teacher education program had applied to the university through the English national teacher education application scheme. A minority of those accepted for pre-service training were drawn from the host university's undergraduate and postgraduate science courses. The majority arrived as graduates from science degree courses from a wide range of UK universities and a small number of overseas universities (see Tables 1, 2, 3 and 4).

The majority of respondents were aged between 20 and 29 years (59%), with 26% being aged 30 to 39. There were slightly more women (57%) than men (43%).

From a subject perspective, the undergraduate degrees held by trainees ranged from Japanese Language and Society to Equine Studies. In cases where the initial degree was in a non-scientific discipline or a science-related discipline (e.g., engineering), trainees had completed a six-month subject knowledge enhancement course in either physics or chemistry as a condition of an offer of a place on a pre-service training program. The most popular initial science degrees were biology (19%), chemistry (11%), biochemistry (11%) and physics (10%). Looking at the highest academic award attained by respondents, 78% held only a bachelor's

Table 1 Gender profile of survey respondents

	Number	Percentage
Female	**107**	**56.6**
Male	**82**	**43.4**
Total	**189**	**100.0**

Table 2 Age profile of survey respondents

Age range	Number	Percentage
50 to 59	6	3.2
40 to 49	21	11.1
30 to 39	50	26.5
20 to 29	112	59.3
Total	189	100.0

degree, 13% were qualified to the master's level and 9% held doctorates in science or science-related fields.

Categorization of respondent responses

The questionnaire was designed to allow respondents to provide, in their own words, definitions of key scientific terminology. This was, in essence, a scoping exercise designed to identify and outline the meanings and/or parameters of this scientific terminology. In all, a number of categories of response were constructed (see Table 5) from standard definitions of terms obtained from the Oxford Concise English Dictionary and the Chambers Dictionary of Science and Technology (Walker, 1999, Thompson, 1995). The use of a specialist and general dictionary ensured that common and technical meanings were included in the categories for the terms under investigation. For example, a definition of 'fact' that contained any reference to either truth, proof/proven, or reality (TPR) in its definition was placed within that category. A definition of a fact that contained reference to something that has happened or has been seen, would be placed in the category of 'known to have occurred/existed' (KOE).

As respondents were free to write down whatever definition came to mind, rather than ticking off a given statement or set of statements, a 'best fit' model was used to allocate the definitions used into categories. The aim of this mapping exercise was to see the range and variety of definitions that science graduates would provide. As such, the research reported here is a scoping study where the intention is to look at the range of possible definitions.

An alternative to open responses could have been the provision of a smaller range of definitions which respondents could choose and which most closely matched their own ideal definition. This was rejected on the grounds that the initial choice of definitions by the researcher may introduce a response bias. Taking an 'open response' approach, however, means that quantitative analysis (e.g., significance testing to see if there is an increased/decreased likelihood of certain groups responding in certain ways) may be unreliable due both to the spread of responses and the small number of cases in each category. In this study, results between observed

Table 3 Subject profile of survey respondents

PGCE subject	Number	Percentage
Physics	37	19.6
Chemistry	62	32.8
Biology	90	47.6
Total	189	100.0

Table 4 Academic award profile of survey respondents

Highest academic award	Number	Percentage
Doctoral	16	8.5
Masters	25	13.2
Bachelors	148	78.3
Total	189	100.0

Table 5 Categorization of respondent definitions

Theory	Code
Unproven Ideas	UPI
A system of Ideas	SOI
Evidenced Ideas	EVI
Evidenced Ideas, not yet a Law	EINL
A guess/Guesswork	GUE
Proven Hypothesis	PRH
Tested Hypothesis	THE
No definition	ND
Other definition	OD
Fact	
Evidence or verified Information	EVI
Truth, proven or reality	TPR
Known to have occurred/existed	KOE
A Datum point	DAP
No Definition	ND
Other definition	OD
Law	
Rule or generalization for natural phenomena	RNP
Proven with no exceptions/doubt	PNE
Rule that governs behavior in society	RBS
Proven theory/hypothesis	PTH
Ideas for hypothesis generation	IHG
No Definition	ND
Other definition	OD
Hypothesis	
Testable Idea/Prediction	TIP
Prediction based on evidence	PBE
Prediction	PRE
Prediction based on theory	PBT
Educated guess	EDG
Untested theory	UNT
No Definition	ND
Other definition	OD

differences are therefore taken to be indicative of tendencies for science graduates to define and use key terminology in a particular way. From this scoping exercise a new survey instrument could be produced to enable a further study and analysis to take place to establish any patterns in the way in which certain groups (age, gender, subject, etc.) define terms.

Results

Definitions of theory

The definitions of theory provided by respondents (see Figure 1) fell broadly into two areas: unproven ideas (UI) 29.1% and an explanatory system of ideas (ESI) 24.9%. Graduates with a background in chemistry and physics tended to define theories as ESIs (24.3%), whereas biologists tended to define them as unproven ideas (34.4%).

Typical responses for the ESI category of definitions include:

> *'an idea that has not been proven'; 'an idea of how something works/happens that hasn't been proven true'; the ideas behind experiments* (biologists); *'A prevailing interpretation of a phenomenon – not yet a law'* (psychologist); *'a rationale or working idea that explains the observed phenomena to date and leads to predictions for future situations'* (Chemist); *'a proposition observed to be true but subject to experimental/observational modifications'* (physicist).

Definitions of fact

The definitions of a fact (see Figure 2) fell broadly into two categories. Nearly two thirds of respondents (65.6%) equated a fact with 'truth, proven or reality' (TPR) while just under a quarter of respondents (24.3%) defined a fact as 'evidence or verified information' (EVI). Physics students had less of a tendency to define a fact as TPR (43.3% as compared to 73.3% of biologists and 67.7% of chemists). A total of 32.4% of the physicists' definitions tended to fall in the EVI category. A total of 76% of respondents in the youngest age category defined a fact in the TPR category as age increased the percentage of definitions of a fact as TPR reduced, with older respondents defining it as EVI.

Typical responses in the TPR category included defining a fact as, *'an aspect of experience that is indisputably true'* (physicist)*; 'something that has been proven beyond reasonable doubt'* (biologist); *'a piece of knowledge/information that has been experimentally proven'* (chemist).

Definitions of 'law'

This term provided the greatest number of respondents who chose to define the term not in scientific terms, but in vernacular terms (see Figure 3). Less than one-third (30.2%) of respondents defined a law as a 'rule or generalization of natural phenomena', although 24.9% did state that laws were proven without exceptions or doubt. A total of 20.6% simply defined a law in terms of rules for society. More women tended to define a law as a rule in society (25.2%) than did men (14.6%).

Definitions of hypothesis

The term 'hypothesis' was the best understood and defined term (see Figure 4). One-third of the respondents (33.3%) defined a hypothesis as a testable idea/prediction with a further quarter (25.3%) defining it as a prediction based on evidence. A total of 10.6% defined it simply as a prediction: 13.8% defined it as a guess or an educated guess. There were no apparent subject or gender differences in response to this item.

Discussion

Key terminology was not well defined (certainly not consistently) by the science graduates in this study. This study has demonstrated that there is persistent inconsistency in the definitions of key scientific terms within the ranks of science researchers and science educators. This raises a potential problem when teaching science in high schools. For example, the notion that a fact is somehow 'the truth' will be at odds with an accepted concept of science - which is not about 'truth', but about knowledge and understanding of natural phenomena. Facts in science can, and do, change. For example, evidence and understanding of the idea of 'fixed continents' was scientific 'fact' until the 1960s when the theory of plate tectonics was developed to explain how continents have moved over the surface of the earth (Williams, 2011).

A key question here is whether or not the situation described reflects how science teachers in general will treat scientific terminology, such as theory, fact, law and hypothesis. If we accept that theories in science are explanatory models of the data/observations and that they are based on evidence, it is worrying that only 25% of science graduates describe theories as a form of evidenced explanation. A total of 11% of the physicists responding thought of theories as evidenced ideas that are not yet laws, indicating that their concept of the status of these key terms is somehow hierarchical - leading from hypothesis to theory and finally to a law. This probably reflects the character of physics as a 'law-laden' discipline in which an objective of physics is to discover the 'laws' of nature.

When we consider descriptions of the status of hypotheses, theories and laws, we can see that hypotheses and theories are explanatory and that laws and principles in science are descriptive. There is no hierarchy that dictates that theories will, with enough evidence, graduate to becoming laws or even principles in science.

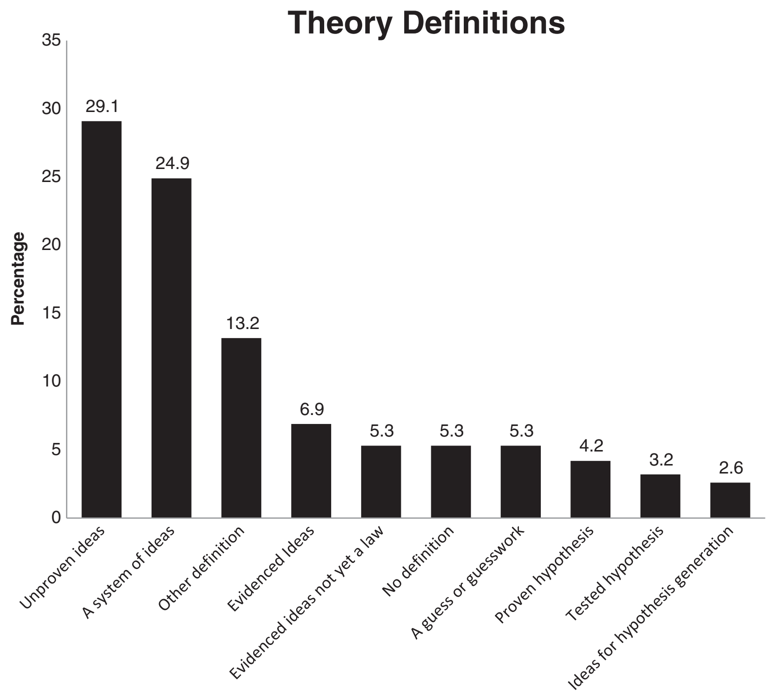

Figure 1 Percentage frequencies of theory definitions.

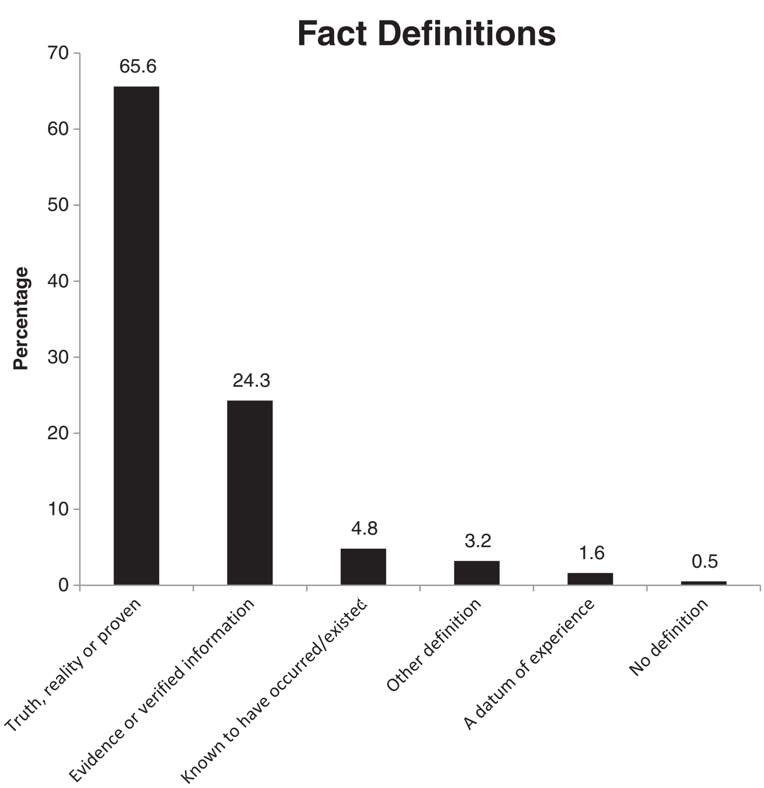

Figure 2 Percentage frequencies of fact definitions.

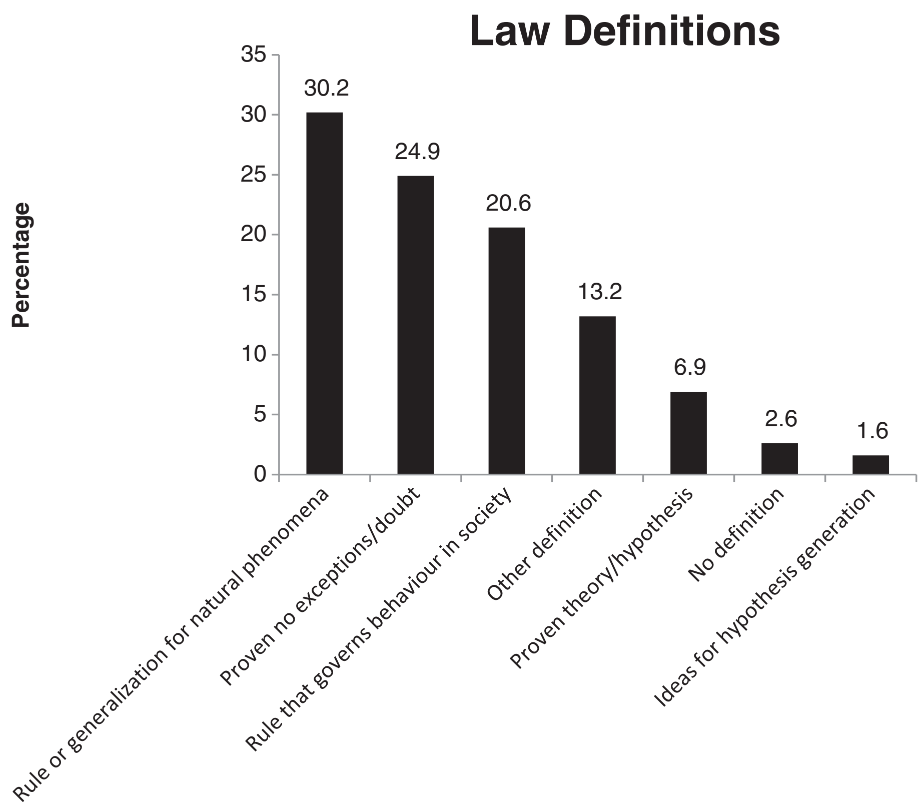

Figure 3 **Percentage frequencies of law definitions.**

It is also worth noting that as a discipline biology contains few 'laws'. Even those aspects of biology which purport to be laws, e.g., Mendel's law of independent assortment, or Mendel's law of segregation, may not fully conform to the generally accepted conditions that a scientific law should meet (Press, 2009). As Mitchell (2000, p.246) states, *'Scientific laws allow us to explain, predict, and successfully intervene in the world.'* In this sense, Mendel's laws would allow us to make predictions. Mitchell then describes the features which allow theories to accomplish these functions as:

1. logical contingency (they have empirical content),
2. universality (they cover all space and time),
3. truth (they are exceptionless), and
4. natural necessity (they are not accidental).

In biology, even with 'accepted' laws, such as Mendel's laws, we cannot claim that they are 'exceptionless'. For example, we know that not every gene has alleles that are strictly dominant or recessive. The characterization of biology as a subject with few laws is explained by Mayr (1982),

> *Generalizations in modern biology tend to be statistical and probabilistic and often have numerous exceptions. Moreover, biological generalizations tend to apply to geographical or otherwise restricted domains. One can generalize from the study of birds, tropical forests, freshwater plankton, or the central nervous system but most of these generalizations have so limited an application that the use of the world law, in the sense of the laws of physics, is questionable.* (p.19)

Conclusion

Scientific language is necessary for clear communication, but its use by science teachers has not been sufficiently researched with respect to differing definitions of key scientific terminology. Research, e.g., by Lemke (1990), shows that talking science, rather than talking *about* science, is more than just using technical vocabulary. He recommends that children are given more practice in talking science, shown how to combine science terms in complex sentences and are encouraged to translate between scientific and colloquial statements. This last point is a key factor in increasing scientific literacy.

If science teachers are using variable and various definitions of key scientific terminology, Lemke's goal will be very difficult to achieve. In this respect, the training that pre-service science teachers undertake should address and explore definitions of key terms to ensure that more consistent and scientifically acceptable definitions

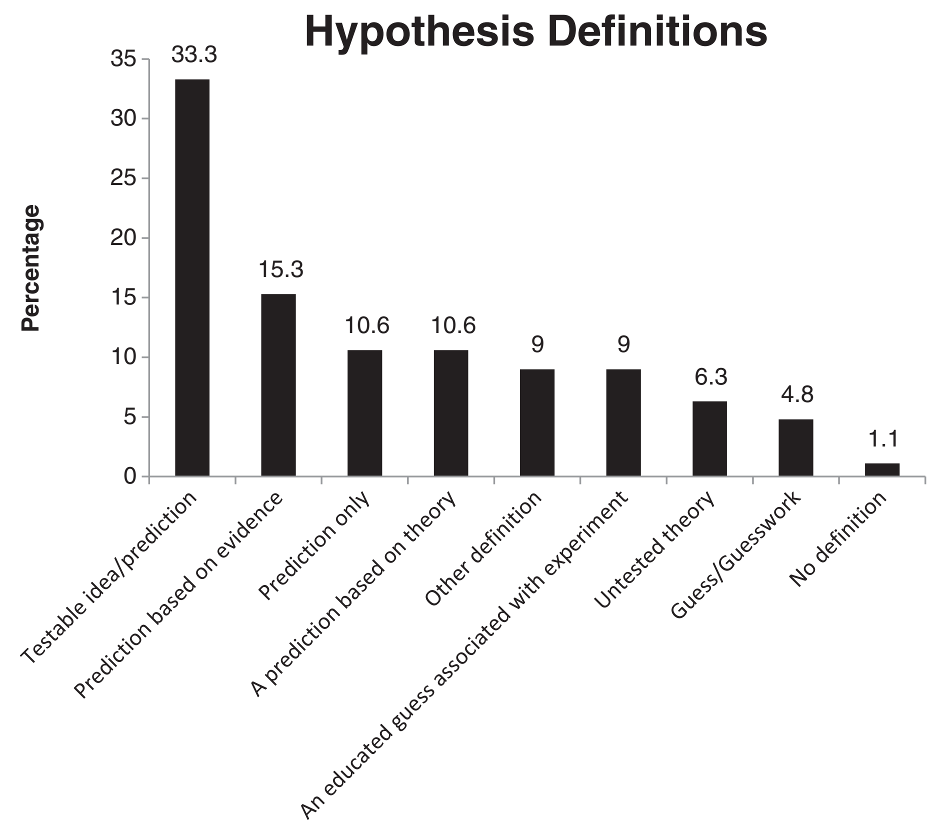

Figure 4 **Percentage frequencies of hypothesis definitions.**

are used in their everyday teaching. How such terms are used in the day-to-day teaching materials (e.g., textbooks and resources) should also be considered by textbook writers and curriculum developers.

If a goal of science education is scientific literacy, then being able to differentiate between the use of terminology in a scientific context and an everyday context should be a core requirement of science education, as recommended above. Given the ease with which such terminology can and is used interchangeably, I would argue that science educators should adopt a pragmatic approach to teaching children the difference between a scientific and a non-scientific theory/fact/law/hypothesis/principle. Analysis of teaching materials that originate from non-scientific publications, e.g., newspapers, would be a useful starting point to open discussion with children on how scientists use terminology and how this differs from everyday usage. Misconceptions and misunderstandings are common in science and, for science educators, addressing these is part and parcel of everyday teaching. One useful resource that clearly sets out to address a wide range of common misconceptions and misunderstandings, including incorrect definitions of scientific terminology, is the Understanding Science website produced by the Museum of Paleontology at the University of California at Berkeley (Thanukos, 2013).

One possible approach that could improve children's understanding of the special nature of some of the words used in science may be the adoption of the prefix 'scientific' before such words as 'theory', 'law', 'fact', 'hypothesis', 'principle', to distinguish them from their common everyday use. Adopting the prefix 'scientific', to help separate common meaning from a more precise scientific meaning, may help to reduce misunderstandings and strengthen the discipline of science. This survey indicates that even when a context is clearly signposted (the survey was called 'Scientific Words and Meanings'), many respondents still provided an everyday definition for the word 'law'. The location (where the survey was completed) was also, though not exclusively, in a science laboratory. Given that science graduates in the context of learning to be science teachers, often located within a science laboratory, still provide a common meaning over a scientific one for some terminology is interesting and, I would argue, reinforces the idea that the use of the prefix 'scientific' would be helpful. Further research is needed to see if such a prefix does enhance and improve how such words are defined.

Unless teachers of science and their students understand the different uses of key scientific terminology and operate with an appropriate degree of precision and consistency in their definitions, then there will continue to be confusion about what certain words mean and their status in different contexts.

Abbreviations
ESI: explanatory system of ideas; EVI: evidence or verified information; KOE: known to have occurred/existed; TPR: truth, proof/proven, or reality; UI: unproven ideas.

Competing interests
The author declare that he have no competing interests.

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References
Crosland, MP (2006). *The Language of Science: from the Vernacular to the Technical*. Cambridge: Lutterworth Press.
Devlin, H (2010). Unearthly life forms are no longer and Alien Concept. *The Times (London) p.36*.
Gyllenpalm, J, Wickman, P-O, Holmgren, S-O. (2010). Teachers' language on scientific inquiry: methods of teaching or methods of inquiry? *International Journal of Science Education, 32*(9), 1151–1172.
Halliday, MAK (2003). *The Language of Science*. London: Continuum.
Kent, W. (1958). Scientific naming. *Philosophy of Science, 25*(3), 185–193.
Lemke, JL (1990). *Talking Science: Language, Learning, and Values (Language and Classroom Processes* (Vol. 1). London: Ablex Publishing.
Mayr, E (1982). *The Growth of Biological Thought: Diversity, Evolution, and Inheritance*. Cambridge, MA: Belknap Press.
Mitchell, S.D. (2000) Dimensions of Scientific Law. *Philosophy of Science, 67*(2), 242–265.
Press, J (2009). Physical explanations and biological explanations, empirical laws and a priori laws. *Biology and Philosophy, 24*(3), 359–374.
Reeves, C (2005). *The Language of Science (Intertext)*. London: Routledge.
Snow, CE. (2010). Academic language and the challenge of reading for learning about science. *Science, 328*(5977), 450–452.
Teaching Learning and Research Programme, T (2006). *Science Education in Schools: Issues, Evidence and Proposals*. London: Institute of Education.
Tenopir, C, & King, DW (2004). *Communication Patterns of Engineers*. Hoboken, NJ: Wiley-Blackwell.
Thanukos, A (2013). *Tips and strategies for teaching the nature and process of science [Online]*. Available: http://undsci.berkeley.edu/teaching/misconceptions.php#a1 [Accessed 8th March 2013].
Thompson, D (Ed.). (1995). *The Concise Oxford Dictionary*. Oxford: Oxford University Press.
Walker, PMB (Ed.). (1999). *Chambers Dictionary of Science and Technology*. Edinburgh: Chambers Harrap.
Webb, P. (2010). Science education and literacy: imperatives for the developed and developing world. *Science, 328*(5977), 448–450.
Wellington, J, & Osborne, J (2001). *Language and Literacy in Science Education*. Buckingham, UK: Open University Press.
Williams, JD (2011). *How Science Works: Teaching and Learning in the Science Classroom*. London: Continuum Books.

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